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ENVIRONMENTAL EFFECTS ON MICROSEISMIC WAVE PROPAGATION.(U)
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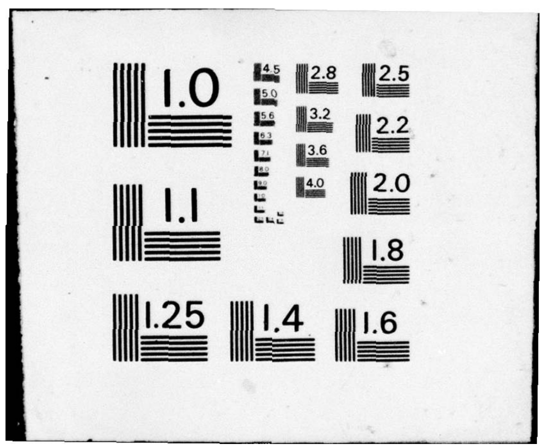
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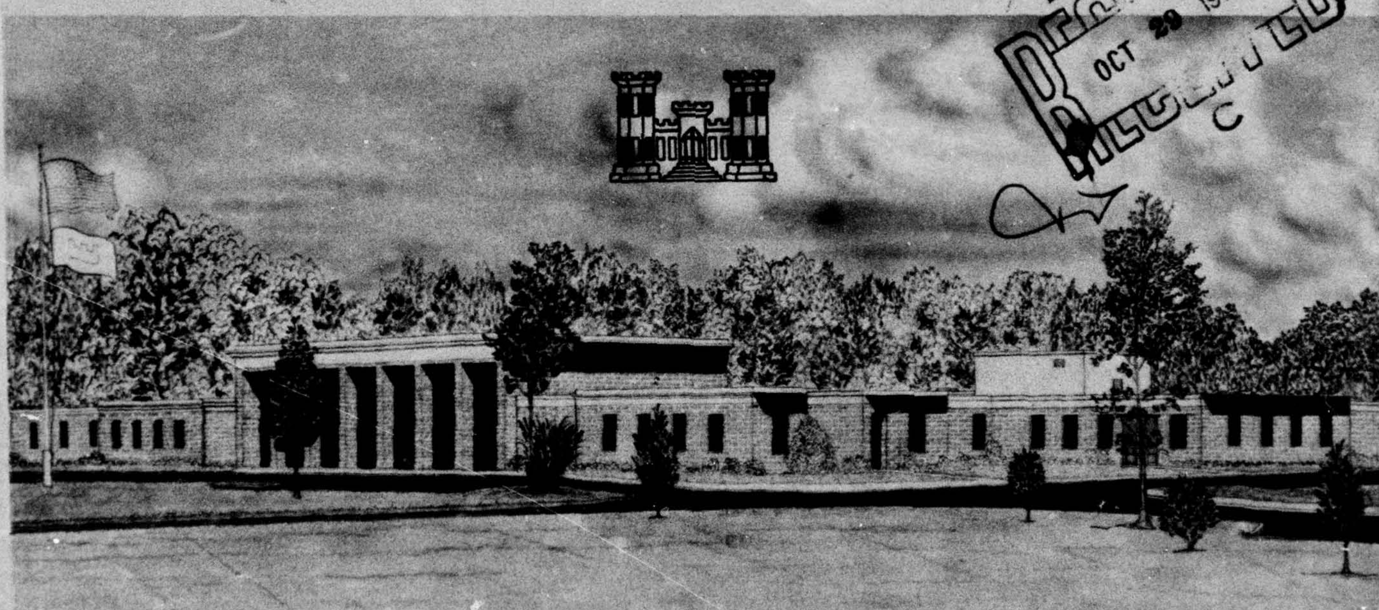

June 1973

Sponsored by Office, Chief of Engineers, U. S. Army

Conducted by U. S. Army Engineer Waterways Experiment Station
Soils and Pavements Laboratory
Vicksburg, Mississippi

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Foreword

This investigation was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) under the sponsorship of the Office, Chief of Engineers (OCE), Military Engineering Research (MER) programs, appropriation No. 21X2040 108-3508 P501B. The study was conducted during the period January to May 1971 in order to determine certain environmental effects on microseismic wave propagation.

This report was prepared under the supervision of Mr. R. F. Ballard, Jr., and the general direction of Messrs. J. P. Sale, R. G. Ahlvin, and R. W. Cunny of the Soils and Pavements Laboratory, WES. The report was written by Dr. W. F. Marcuson III, Soils and Pavements Laboratory.

Director of WES during the preparation and publication of this report was COL Ernest D. Peixotto, CE; Technical Director was Mr. F. R. Brown.

Contents

Summary

This reports the results obtained from a multiple regression analysis that was conducted on seismic data collected during field measurement of motion originating from an impulse source. Equations that predict the maximum distance at which a ground seismic intrusion detector (GSID) can detect a man walking are given. The independent variable in these equations is the thickness of the soil overlying a hard layer.

ENVIRONMENTAL EFFECTS ON MICROSEISMIC WAVE PROPAGATION

Background

1. The term "microseismic wave propagation" as used herein is defined as the movement of waves, whose amplitude is considerably smaller than that produced by an earthquake, through the earth's crust. More insight and knowledge of this movement may lead to better and more advanced techniques for use in intrusion detection, security, and associated areas.

2. Present knowledge has established the fact that wave propagation through the earth's crust is a very complicated phenomenon. The earth's crust is, in general, a heterogeneous, dispersive, anisotropic medium; consequently, an exact analytical solution using the classical theory of elasticity for wave propagation is highly unrealistic. Much has been published in the literature on wave propagation through a homogeneous, isotropic, linearly elastic medium. For certain problems, this description of the medium is adequate and its use will yield generalized solutions; however, these solutions are functions of the elastic properties of the material and do not account for substrata discontinuities often encountered within the earth's crust. Therefore, the solution obtained is no better than the accuracy of the description of the material and environmental properties that are used as input. The material must be described in terms of its elastic properties, i.e. the shear modulus G and Young's modulus E. Both E and G have been expressed as functions of wave velocity, density, void ratio, effective stress, and plasticity index.

3. The solutions obtained using the approach mentioned above do not adequately describe field propagation phenomena. Consequently, there is a need for another approach to realistically describe the parameters influencing seismic wave propagation through near-surface materials. Numerous field experiments using steady-state vibratory and

various types of impulse sources have demonstrated that an empirical relationship could be developed to predict the attenuation of microseismic waves in layered soil material. It is anticipated that this relationship will be a function of easily determinable soil parameters.

4. This study is a first attempt to relate environment properties such as (a) soil depth, (b) soil type, and (c) vegetation to wave propagation potential. In this report wave propagation potential is denoted by the distance from a given source at which a wave can be detected using a given seismic sensor. From the results obtained it is hoped that a more accurate estimate of a site's wave propagation characteristics can be made.

Purpose

5. The purpose of this study was to (a) develop a method of analysis that would yield a model capable of predicting the seismic response of a particular site, and (b) determine the existence of any soil parameters other than the elastic constants which could be used to predict soil response and seismic wave propagation characteristics at a given site. These parameters were to be used as independent variables and correlated with seismic response (maximum detection distance) to form a prediction model. This model was to contain only the more significant parameters and was to be fabricated in a simple and usable form.

Scope

6. Several techniques were considered for obtaining field data that could be used to study the effect of soil parameters and environmental conditions such as temperature, vegetation, ground slope, etc., on wave propagation through the soil. It was decided that the scope of this investigation would be limited to seismic field data originated from impulse rather than steady static sources. This decision was based largely on emphasis the Department of the Army has placed on its seismic sensor program. The information obtained from a study of this type has

immediate and direct application to the current work being done in the seismic sensor intrusion detection area.

7. A review of the literature produced a minimum of good field data in this area. This information was furnished to the U. S. Army Engineer Waterways Experiment Station (WES) by the Sandia Coporation, Albuquerque, N. Mex. These data, which were obtained with a ground seismic intrusion detector (GSID) developed by Sandia Corporation, included detection distance (for a man walking), depth of soil, a description of the soil, a description of the vegetation, site location, and, in some cases, the frequency of the seismic signal. These data were collected at various locations, both in the continental United States and abroad. A regression analysis was conducted on these data using a statistical program developed by Mr. J. H. Goodnight of the Experimental Statistics Department at North Carolina State University, Raleigh, N. C. This program was run on a GE-600 computer.

Description of the Computer Program

8. The computer program can be subdivided into four parts. The first part, part I, is used to input both dependent variables (variables to be predicted) and independent variables (variables used to predict). These variables comprise the measured data or data bank. New variables can be generated as functions of measured variables. For example, frequency and soil depth might be measured variables, and a new variable (frequency times the square root of soil depth) might be generated. The program is presently limited to a total of 75 variables including dependent and independent variables (both measured and generated).

9. In part II the simple statistics of each variable are computed. In this case simple statistics refers to the sum, mean, sum of the squares, variance, and standard deviation. Bivariant statistics can also be computed. Here each variable is correlated with every other variable (one at a time). This analysis helps determine if measured variables are interrelated.

10. In part III the dependent variable is specified and the

computer searches the independent variables (first one at a time, then two at a time, then three, etc.) to see what variable and/or combination of variables correlates best with the dependent variable.

11. Based on the results of part III the dependent variable and independent variables are specified; the computer then uses the Doolittle matrix inversion technique to generate the regression equation. This equation is of the form:

$$Y = B_0 + B_1X_1 + B_2X_2 , \dots , B_iX_i$$

where

$$Y = \text{dependent variable}$$
$$X_1, X_2, \dots X_i = \text{independent variables}$$
$$B_0, B_1, B_2, \dots B_i = \text{regression coefficients}$$

This equation is the equation of best fit through the data. "Goodness of fit" is measured by the value of the squared correlation coefficient (r^2). If the r^2 value is 1, perfect correlation has been obtained. If the r^2 value is 0, no correlation has been obtained.

Site Selection and Layout

12. The data compiled for use in this study were gathered from the following areas:

Location	No. of Sites	Date of Testing
West Germany	30	Sep-Oct 70
Fort Hood, Tex.	28	Apr 70
South Vietnam	6	Sep 70
Baraboo, Wis.	4	Dec 70
Chula Vista, Calif.	3	May 70
Panama	2	Mar 70
Great Britain	2	Oct 70

(Continued)

Location	No. of Sites	Date of Testing
Fort Bliss, Tex.	1	Nov 67
Camp Pendleton, Calif.	1	Feb 70
29 Palms, Calif.	1	Feb 70
Tonopah, Nev.	1	Jan 70
Eglin Air Force Base, Fla.	1	Oct 68
Total	80	

The site locations were chosen so as to give a wide range of environmental characteristics. The test sites were laid out in the following manner. First, a 120-m straight line was staked off. This line was then subdivided into twenty-four 5-m segments and marked, starting with zero at the center of the line and increasing in both directions (see fig. 1).

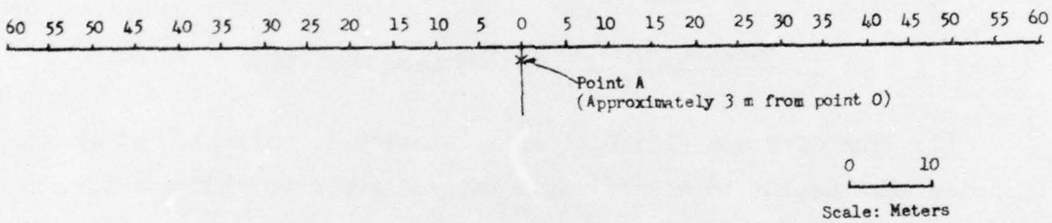

Fig. 1. Typical site layout

At the point marked zero, a second line was staked off perpendicular to the first line. A distance from the first line of approximately 3 m on the second line was marked. This location was identified as point A, thus completing the site layout.

Test Procedure

13. With the site layout complete, a GSID was placed on the ground surface at point A. The GSID was activated, and the gain control was set at a specific range setting. The sensitivity of the instrument can be varied by adjustment of the gain control. A man then walked down the line, and the distance at which the detector first indicated ground motion was recorded. He continued to walk, passing station zero, until

no motion was registered. This distance was also recorded. The gain control was then changed to other range settings and the man repeated the walk. In this manner the extreme distance at which a man walking could be detected by a GSID and the particular gain setting used were recorded. In some cases, additional electronic equipment was used that enabled operators to record the ground-motion signal and, in turn, determine the frequency of the wave being received; however, this was done at only approximately 50 percent of the sites. The site environmental data were then recorded. These data included a qualitative description of the soil and of the vegetation. In addition, the depth of soil to a hard layer (rock or heavily overconsolidated soil) was determined. If such a layer was deeper than 3 m, it was recorded as "+3 m." These depths were determined by both hand auger and visual estimation. The visual estimate was based on existing terrain features, air photos, etc.

Presentation of GSID and Site Data

14. The GSID and site data are presented in table 1. It should be noted that depths to a hard layer ranged from 0 to +300 cm; i.e. any depth to rock greater than 300 cm was listed as +300.

Analysis and Results

15. Sensor response was emphasized during the testing program. Minimum effort was expended to describe soil (surface and subsurface) and vegetation conditions. With this qualitative data, attempts were made to quantitatively describe each site. In order to do this a number was assigned to each soil type, i.e. rock = 0, sand = 1.0, silt = 2.0, and clay = 3.0. With this system a silty clay would be a 2.5. Soil homogeneity was also ranked; i.e., good = 1.0, medium = 2.0, and poor = 3.0. With this system a uniform sand would have a homogeneity of 1.0 and rocky clay might be 3.0. Vegetation was also ranked in the following manner: no vegetation = 1.0, grass = 2.0, trees = 3.0, and jungle = 4.0.

16. The system mentioned above was used to describe data collected at sites in West Germany; at Fort Hood, Tex.; Baraboo, Wis.; Chula Vista, Calif.; and in England and these descriptions were fed into the computer. The variables were subdivided as follows:

Dependent variable

X_1= detection distance of GSID at gain 5, m

Independent variables

X_2 = soil depth, m

X_3 = soil homogeneity

X_4 = soil type

X_5 = vegetation

X_6 = frequency, Hz

X_7 = logarithm of X_2

$X_8 = X_2^2$

It should be noted that when frequency was not determined it was recorded as zero. It was found that the best combination of three variables was X_2 , X_3 , and X_4 . These variables fit the data with an r^2 value of 0.70. If only one independent variable is used, X_2 fits the data best with an r^2 value of 0.66. Several other attempts were made to correlate the data using this crude quantitative environmental site description. Since the addition of X_3 and X_4 only increases the r^2 value 0.04, it was concluded that this type of site description does not significantly improve the ability to predict detection distance, and that X_2 was the most significant of the measured variables.

17. Next the data were subdivided into two groups: (a) data points with frequency measurements and (b) data points without frequency measurements. The detection distance obtained at gain 5 was the only detection distance used in this analysis, because more data were available for gain 5 than either of the other gains. Often no detection distance was determinable at gains 4 and 3 or no data were taken at these gains.

18. A regression analysis was conducted on the data in group a. Various functions of depth and frequency were tried as the independent variable, keeping the detection distance as the dependent variable. From this analysis, it appears that the simplest equation of best fit is

$$X_1 = 7.57 + 3.97\,X_2^2 \qquad (1)$$

where

X_1 = detection distance of GSID at gain 5, m

X_2 = depth to a hard layer (≤ 3 m), m

Equation 1 fits the data with a correlation coefficient r of 0.7115. This model is limited by the restricted amount of available data, use of only one independent variable X_2, and because the phenomenon of wave propagation is obviously a function of other environmental characteristics. In this light, an r value of 0.7115 is considered both reasonable and acceptable.

19. Table 2 shows the detection distances predicted by equation 1, the actual observations, and the differences between the predicted and observed distances.

20. If equation 1 is divided by two and rounded off to the nearest whole number, i.e.,

$$X_1 = 4.0 + 2.0\,X_2^2 \qquad (1a)$$

it would yield a conservative value of X_1 approximately 85 percent of the time. By conservative, it is meant that the predicted detection distance is less than the observed detection distance. Equation 1a is not conservative for sites 10, 35, 60, 66, and 74 (see table 2). Next, as a check, equation 1 was used to predict values from the data in group b, which were not used to generate this equation. Table 3 is a tabulation of typical results of this exercise. The analysis indicates that equation 1 yields reasonable prediction about 60 percent of the time. However, if the predicted values are divided by 2 they are less than the observed value (conservative) most of the time. Therefore equation 1a can be used to conservatively predict the distance at which

the GSID can detect a man walking. Since X_2 can never be negative, the minimum detection distance predicted by equations 1 and 1a is 7.57 and 4 meters, respectively.

21. A second regression analysis was conducted, this time using all the data (groups a and b). This analysis showed that

$$X_1 = 7.38 + 3.97\, X_2^2 \qquad (2)$$

is the simplest equation of best fit. This equation fits the data with a correlation coefficient of 0.772. Table 4 presents the predicted values using equation 2, the observed values, and differences. A study of table 4 indicates that equation 2 predicts detection distances within 25 percent of observed detection distances approximately 75 percent of the time, if sites with observed detection distances of less than 6 m are neglected.

22. If equation 2 is reduced by one-half, then

$$X_1 = \frac{1}{2}\left(7.38 + 3.97\, X_2^2\right) \approx 4.0 + 2.0\, X_2^2 \qquad (2a)$$

If this modification is applied to table 4, equation 2a gives a conservative prediction (less than observed) approximately 85 percent of the time.

23. All the equations presented in this report are parabolas. This indicates that the detection distance varies as the square of the soil depth. When the thickness of soil is small (approaches 0), equations 1a and 2a predict a constant detection distance of approximately 4 m. Since the soil thickness can never be negative these equations are unable to predict detection distances less than 4 m.

Conclusions

24. It should be emphasized that the conclusions drawn in this report are based on limited data. The following are the primary conclusions, as indicated by the results of this study.

- a. If the subsurface conditions (depth to rock) to a depth of 3 m are known, a conservative estimate of the detection distance can generally be made. This detection

distance is a measure of the site's ability to propagate a signal.

b. A mathematical model developed to predict the distance at which a GSID seismic sensor will detect a man walking is least reliable when the soil layer thickness X_2 is small. The minimum predictable detection distance exists when $X_2 = 0$. For this case, $X_1 \approx 7.5$ if regression equations 1 and 2 are being used and $X_1 \approx 3.75$ if equations 1a and 2a are used.

c. It appears that the distance at which a signal can be received by a seismic geophone varies as the square of the depth of soil above a hard layer.

Recommendation for Future Research

25. As a result of this investigation, it is believed that if data were available which yielded more information about the site environment, a better and more reliable model could be developed. It is recommended that data be collected in which the following are measured:

a. Water content

b. Density

c. Void ratio

d. Cone index

e. Layer thickness

f. Compression and shear wave velocities

g. Predominant frequency

h. Background noise

i. Temperature (soil and air)

j. Wind speed and direction

k. Vegetation conditions

l. Detection distance--from a footstep and a controlled energy source

The seismic information should be obtained with calibrated instrumentation and trained personnel. Presently, the WES is obtaining data that will include these parameters. It is recommended that a similar study be conducted incorporating these parameters in a multiple regression analysis.

Table 1

GSID Data and Site Description

Site Location	Site No.	Detection Distance, m for Indicated Gain 5	4	3	Wave Frequency Hz	Depth to a Hard Layer cm	Site Description Soil	Vegetation
West Germany	1	9	4	No	25, 40	40	Rocky sand	Grass
	2	17	4	No	25, 33	80	Sand	Forest
	3	*	34	27	--	+300	Silt	Grass
	4	25	17	8	25, 30	250	Rocky clay	Grass
	5	5	No	No	--	150	Clay and sand	Marsh
	6	23	4	No	35	150	Rocky sand	Grass
	7	21	4	0	--	100	Sand	Forest
	8	26	17	11	20, 35	250	Gravelly sand	Grass
	9	20	7	3	--	150	Rocky sand	Forest
	10	No	No	No	70, 80	25	Rocky sand	Grass
	11	1	No	No	--	10	Rocky sand	Grass
	12	11	5	3	--	100	Rocky clay	Field
	13	*	63	37	--	+300	Alluvial sand	Grass
	14	28	18	4	--	200	Slightly rocky clay	Forest
	15	31	18	12	--	250	Clay	Field
	16	41	29	18	--	+300	Sand	Forest
	17	20	9	5	--	100	Rocky clay	Field
	18	1	No	No	--	25	Rocky clay	Field
	19	5	0	No	--	30	Rocky clay	Grass
	20	*	30	27	--	+300	Clay	Grass
	21	35	27	7	50, 55	+300	Gravelly sand	Forest
	22	21	8	4	30, 35	85	Clayey sand	Grass
	23	38	26	8	--	+300	Sand	Grass
	24	33	22	11	25, 30	+300	Sand	Grass
	25	37	29	15	30, 35	+300	Sand and clay	Grass
	26	4	1	No	65, 80	40	Rocky sand	Grass
	27	27	8	1	--	250	Rocky sandfill	Grass
	28	22	4	0	40	85	Rocky clay	Grass
	29	3	No	No	70, 80	20	Rocky clay	Grass
	30	27	16	9	--	250	Clay	Grass
Fort Hood, Tex.	31	5	No	--	--	25	Rocky, moist	Grass
	32	5	No	--	--	15	Very rocky	Sparse
	33	5	No	--	--	30	Some rocks	Grass
	34	No	No	--	--	10	Very rocky	Sparse
	35	No	No	--	99	10	Very rocky	Sparse
	36	5	3	--	--	10	Dry, rocky	Sparse
	37	6	No	--	65	10	Dry, rocky	Grass
	38	1	No	--	--	15	Very rocky	Sparse
	39	6	6	--	55	60	Moist clay	Grass
	40	1	1	--	--	60	Moist clay	Grass
	41	6	1	--	--	40	Rocky clay	Sparse
	42	8	No	--	--	20	Some rocks, clay	Grass
	43	21	6	--	50	35	Some rocks, clay	Grass
	44	No	No	--	--	15	Rocky, dry	Sparse
	45	18	12	--	--	15	Rocky, dry	Grass
	46	21	12	--	--	75	Dry	Grass
	47	5	No	--	65	10	Rocky, dry	Sparse
	48	5	5	--	--	15	Rocky, moist	Grass
	49	6	3	--	--	20	Rocky clay	Grass
	50	8	3	--	--	20	Rocky clay	Grass
	51	11	3	--	60	55	Moist clay	Grass
	52	8	1	--	--	15	Rocky, dry	Sparse
	53	11	3	--	--	45	Soft, moist	Grass
	54	5	No	--	70	20	Some rocks, damp	Sparse
	55	5	1	--	--	20	Some rocks, damp	Sparse
	56	12	6	--	--	15	Some rocks	Grass
	57	15	5	--	--	10	Rocky, dry	Sparse
	58	16	11	--	--	75	Some rocks, moist	Grass
South Vietnam	59	*	*	18	30, 35	+300	Rocky clay, sand	Scrub
	60	15	N/A	--	45, 70	+300**	Weathered rock	Sparse
	61	*	21	--	40, 65	+300	Rocky clay	Grass
	62	*	*	15	35	+300	Clay, silt, sand	Pasture
	63	*	24	--	40, 50	+300	Clayey silt	Grass
	64	*	24	--	40, 50	+300	Clayey silt	Grass
Baraboo, Wis.	65	*	28	14	50, 70	+300	Sand, moist	Wooded
	66	8	3	No	40, 45	200**	Clayey sand	Field
	67	N/A	6	No	--	10	Rocky	Grass
	68	19	7	1	--	+300**	Rocky clay	Grass
Chula Vista, Calif.	69	*	*	34	20	+300	Damp sand	Barren
	70	21	--	--	35, 50	+300**	Hard dry clay	Sparse
	71	11	--	--	45, 60	30	Rocky, dry	Sparse
Panama	72	35	--	--	25	+300	Loamy clay	Jungle
	73	*	25	--	25	+300	Loamy clay	Ele grass
Great Britain	74	1	No	No	60, 99	10	Clay and chalk	Woods
	75	22	11	9	--	150	Clay	Grass
Fort Bliss, Tex.	76	32	--	--	35	+300	Desert alluvium	Barren
Camp Pendleton, Calif.	77	29	17	--	50	200**	Sandy clay	Grass
29 Palms, Calif.	78	*	35	--	20	+300	Alluvium, rockflour	Barren
Tonopah, Nev.	79	51	24	12	55	+300	Caliche	Barren
Eglin AFB, Fla.	80	*	*	52	40	+300	Sand	Sparse

Note: +300 indicates depth of hard layer was more than 300 cm.
N/A - No data were obtained.
* Because of high background noise at the time of the test no data were taken.
** A possibly erroneous depth measurement.

Table 2

Comparison of Predicted and Observed Detection Distances

Group A (Data with Frequency Measurements)

Site Location	Site No.	Detection Distance, m		
		Predicted	Observed	Difference
West Germany	1	8	9	-1
	2	10	17	-7
	4	32	25	+7
	6	16	23	-7
	8	32	26	+6
	10	8	0	+8
	21	43	35	+8
	22	10	21	-11
	24	43	33	+10
	25	43	37	+6
	26	8	4	+4
	28	10	22	-12
	29	8	3	+5
Fort Hood, Tex.	35	8	0	+8
	37	8	6	+2
	39	9	6	+3
	43	8	21	-13
	47	8	5	+3
	51	9	11	-2
	54	8	5	+3
South Vietnam	59	43	50	-7
	60	43	15	+28
	61	43	35	+8
	62	43	40	+3
	63	43	35	+8
	64	43	35	+8
Baraboo, Wis.	65	43	40	+3
	66	23	8	+15
Chula Vista, Calif.	69	43	70	-27
	70	43	21	+22
	71	8	11	-3
Panama	72	43	35	+8
	73	43	40	+3
Great Britain	74	8	1	+7
Fort Bliss, Tex.	76	43	32	+11
Camp Pendleton, Calif.	77	23	29	-6
29 Palms, Calif.	78	43	65	-22
Tonopah, Nev.	79	43	51	-8
Eglin AFB, Fla.	80	43	120	-77

Table 3

Predicted Detection Distances

Group B (Data without Frequency Measurements)

Site Location	Site No.	Detection Distance, m		
		Predicted	Observed	Difference
West Germany	15	32	31	+1
	19	8	5	+3
	27	32	27	+5
Fort Hood, Tex.	32	8	5	+3
	42	8	8	0
	45	8	18	-10
Baraboo, Wis.	68	43	19	+24
Great Britain	75	17	22	-5

Table 4

Comparison of Predicted and Observed Detection Distances

(Equation 2)

Site Location	Site No.	Detection Distance, m Predicted	Observed	Difference
West Germany	1	8	9	-1
	2	10	17	-7
	3	43	40	+3
	4	32	25	+7
	5	16	5	+11
	6	16	23	-7
	7	11	21	-10
	8	32	26	+6
	9	16	20	-4
	10	8	0	+8
	11	7	1	+6
	12	11	11	0
	13	43	80	-37
	14	23	28	-5
	15	32	31	+1
	16	43	41	+2
	17	11	20	-9
	18	8	1	+7
	19	8	5	+3
	20	43	40	+3
	21	43	35	+8
	22	10	21	-11
	23	43	38	+5
	24	43	33	+10
	25	43	37	+6
	26	8	4	+4
	27	32	27	+5
	28	10	22	-12
	29	8	3	+5
	30	32	27	+5
Fort Hood, Tex.	31	8	5	+3
	32	7	5	+2
	33	8	5	+3
	34	7	0	+7
	35	7	0	+7
	36	7	5	+2
	37	7	6	+1
	38	7	1	+6
	39	9	6	+3
	40	9	1	+8

(Continued)

Table 4 (Concluded)

Site Location	Site No.	Detection Distance, m Predicted	Observed	Difference
Fort Hood, Tex. (Con't)	41	8	6	+2
	42	8	8	0
	43	8	21	-13
	44	7	0	+7
	45	7	18	-11
	46	10	21	-11
	47	7	5	+2
	48	7	5	+2
	49	8	6	+2
	50	8	8	0
	51	9	11	-2
	52	7	8	-1
	53	8	11	-3
	54	8	5	+3
	55	8	5	+3
	56	7	12	-5
	57	7	15	-8
	58	10	16	-6
South Vietnam	59	43	50	-7
	60	43	15	+28
	61	43	35	+8
	62	43	40	+3
	63	43	35	+8
	64	43	35	+8
Baraboo, Wis.	65	43	40	+3
	66	23	8	+15
	67	7	10	-3
	68	43	19	+24
Chula Vista, Calif.	69	43	70	-27
	70	43	21	+22
	71	8	11	-3
Panama	72	43	35	+8
	73	43	40	+3
Great Britain	74	7	1	+6
	75	16	22	-6
Fort Bliss, Tex.	76	43	32	+11
Camp Pendleton, Calif.	77	23	29	-6
29 Palms, Calif.	78	43	65	-22
Tonopah, Nev.	79	43	51	-8
Eglin AFB, Fla.	80	43	120	-77

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13. ABSTRACT

This reports the results obtained from a multiple regression analysis that was conducted on seismic data collected during field measurement of motion originating from an impulse source. Equations that predict the maximum distance at which a ground seismic intrusion detector (GSID) can detect a man walking are given. The independent variable in these equations is the thickness of the soil overlying a hard layer.

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